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Effects of Supplementing Broiler Diets Low in Crude Protein with Essential and Nonessential Amino Acids

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Abstract : A study was conducted to evaluate the effects of adding all essential amino acids (EAA) equal to that of higher CP diets or a mixture of nonessential amino acids (NEAA) to low CP diets on the live performance of broilers during the period of 0 to 21 d. A series of experimental diets comprised primarily of corn and soybean meal were formulated to contain 3,200 ME kcal/kg. Five primary diets were formulated to contain 16, 18, 20, 22, and 24% CP. Requirement levels for EAA (110% of NRC, 1994) were accomplished when necessary by adding crystalline amino acids. In each of these dietary series, diets with 16, 18, and 20% CP were supplemented with additional EAA (Trp, Ile, His, Val, Leu, Arg, Gly and Phe) to bring the content of all these EAA to a level equal to that of the 22% CP diet. Additional diets in each series with 16, 18, and 20% CP were supplemented with a mixture of NEAA (equal parts of Ala, Glu, and Glu-NH2) to provide levels of nitrogen equivalent to that provided by the EAA supplementation in the previous diets. Each of the treatments was fed to 12 replicate pens of 5 male chicks of a commercial broiler strain. The reduction of CP level in the starter diets had a significant influence on the live performance. Decreasing CP levels lower than 22% significantly decreased BW gain and increased the feed conversion ratio (FCR). Adding the EAA or NEAA mixtures to the low CP diets significantly improved the performance but did not completely overcome the adverse effects of the low CP diets.

Key words: Broilers, performance, crude protein, amino acids

Introduction

Fraps (1943) showed that a manipulation of the dietary protein can have various effects on broiler performance. He pointed out that differences occurred in the body weights, feed intake, and especially the carcass composition of birds fed different levels of the dietary protein. Because of the expense of providing sufficient protein to growing broilers, numerous studies have been carried out to investigate the possibility of reducing dietary crude protein (CP) levels. It is generally accepted that the CP in the diet should represent a balance of essential (EAA) or indispensable and nonessential (NEAA) or dispensable amino acids supporting the needs for maintenance and the tissue accretion. Reduction in the dietary CP with supplementing synthetic amino acids may support the live performance equal to high CP diets. There is a common agreement that supplementing diets with Met, the first limiting amino acid, and Lys, the second limiting amino acid, allows the reduction of CP levels to a point (Lipstein and Bornstein, 1975; Lipstein *et al*., 1975; Waldroup *et al*., 1976; Uzu, 1982, 1983). By removing the dietary CP minimum and supplementing with Met and Lys, Waldroup *et al*. (1976) found that the best broiler performance could be obtained during 1 to 8-week of age by meeting EAA needs without considering a particular dietary CP minimum. Uzu (1982, 1983) reduced 4% CP from the 20% grower diets while keeping the body weight (BW) gain by Met and Lys supplementation.

Based on the assumption that the non-essential amino nitrogen may likely become a limiting factor in the low CP formulation and the NEAA limitation is particularly significant in regard to the effects upon the carcass fatness in broilers, Fancher and Jensen (1989a) added Glu to three low CP diets (15.7%, 14.2% and 12.3%, respectively) and brought the CP level equal to the 18% CP diet. However, they failed to restore the BW gain of broilers receiving those three low CP diets from 3 to 6-week of age. They concluded that the reduced growth associated with the three low CP diets was not due to insufficient non-essential amino nitrogen. They also reported that additional Met, Lys, Thr and Arg in a 15.7% CP diet did not support the optimal growth as broilers fed a 18.2% CP diet while only Lys and Met supplement to the 18.2% CP diet could support the growth as well as chicks fed the 22.6% CP diet. Fancher and Jensen (1989b,c) further demonstrated that the performance of broilers was impaired when feeding a low CP diet despite the fact that Met, Lys, Thr, Arg, Trp, and Ile were 7.5% above the NRC (1994) recommendation and potassium content was equal in those diets. Deschepper and DeGroote (1995) stated that the performance of chicks was significantly influenced by the dietary protein regimen. In their study, supplementation of low CP (16.3%) diets with Lys, Met, Arg, Thr, Trp, Ile, Leu, His, Phe, and Val or these ten EAA plus Gly and sodium glutamate as a source of NEAA to the same amount as the 23.1% CP control diet resulted in a significantly lower BW gain. However, the addition of NEAA resulted in a slightly improved FCR. They postulated that the failure of these low CP diets might be explained by the deficiencies of some other amino acids in the low CP diets.

The results from different labs about the performance of broilers fed low CP diets are contradictory. This may be due to differences in the basal diets, assay length, age of chick, or other factors. The purpose of the present study was to investigate the effects on the performance of male broilers from 0 to 21 d fed low CP (16%, 18% and 20%) diets supplemented with synthetic EAA and NEAA equal to that of the higher CP (22%) diet.

Materials and Methods

Diet formulation: Diets were formulated to meet a minimum of 110% of the NRC (1994) amino acid recommendations for the 0 to 21 d broiler. A series of experimental diets comprised primarily of corn and soybean meal of known crude protein content were formulated to contain 3,200 ME kcal/kg, 0.90% calcium, 0.45% non-phytate phosphorus, and 0.23% sodium with minimum dietary electrolyte balance of 200 Meq/kg. The corn and soybean meal used were analyzed for CP (N x 6.25) prior to diet formulation using AOAC (1970) procedures. Five primary diets were formulated to contain 16%, 18%, 20%, 22%, and 24% CP. Requirement levels for EAA were accomplished when necessary by adding crystalline EAA to isocaloric diets. In each of these dietary series, diets with 16, 18, and 20% CP were supplemented with additional EAA (Trp, Ile, His, Val, Leu, Arg, Gly and Phe) to bring the content of all these EAA to a level equal to that of the 22% CP diet, a level we have found to be sufficient to support performance of broilers of this age in previous studies (Si *et al*., 2004; Jiang *et al*., 2005). This added additional N to the diets, with the CP equivalent (N x 6.25) of 2.07, 1.70, and 0.89% for the 16, 18, and 20% CP diets, respectively. In order to determine if any response to the supplemental amino acids was due to specific amino acid needs or to the addition of non-specific nitrogen, aliquots of diets in each series with 16, 18, and 20% CP were also supplemented with a mixture of NEAA (equal parts of Alanine, Glutamic acid, and Glutamine to provide an aliphatic, a dicarboxylic, and a dibasic amino acid) to provide levels of nitrogen equivalent to that provided by the EAA supplementation in the previous diets. This resulted in a total of eleven dietary treatments. The crude protein and metabolizable energy values of supplemental amino acids (NRC, 1994) were considered in formulation of the basal diets but not in addition of the EAA or NEAA mixtures. Diets were supplemented with complete vitamin and trace mineral mixes obtained from a commercial integrator. All diets were analyzed for crude protein and for total and supplemental amino acid content by a laboratory specializing in amino acid analysis. The composition of the five basal diets is shown in Table 1. Each of the 11 treatments was fed to twelve replicate pens of five male chicks. Diets were provided in mash form.

Chicks and housing: Male chicks of a commercial broiler strain were obtained from a local hatchery where they had been vaccinated in ovo for Marek's disease and had received vaccinations for Newcastle Disease and Infectious Bronchitis post hatch via a coarse spray. They were placed in compartments in electrically heated brooders with raised wire floors. Five chicks were placed in each of 132 compartments. The test diets and tap water were provided for the ad libitum consumption from 1 to 21 d of age. Continuous 24 hr fluorescent lighting was provided. Care and management followed recommended guidelines (FASS, 1999)

Measurements: Birds were group weighed by pen at 21 d. Feed consumption during the period was determined by weighing the feed container at the start and the end of the study. Mortality was checked twice daily; birds that died were weighed with the weight used to adjust the feed conversion (FCR = total feed consumed ÷ (weight of live birds + weight of dead birds)). At 18 d, feces were collected by pen for one day on aluminum foil and placed in a freezer. The samples were then freeze-dried, ground using a 2 mm screen, and allowed to equilibrate to ambient temperature and humidity. Nitrogen content of the samples was then determined.

Data analysis: Pen means served as the experimental unit. Mortality data were transformed to; data are presented as natural numbers. Data were subjected to the analysis of variance (SAS Institute, 1991) as a single factor arrangement using the General Linear Models procedure. The means for treatments showing significant difference in the analysis of variance were compared using the least significant difference procedure. All statements of significance are based on the 5% level of probability.

Results and Discussion

Calculated and analyzed values for CP and amino acid content are shown in Table 2. Analyzed CP values for all diets were in good agreement with the calculated values. Analyzed levels of all supplemental amino acids were all in close agreement with the calculated values. The amino acid content in all diets was higher than the NRC (1994) recommendation for essential amino acids. Reduction of CP level in the diets had a significant influence on the live performance of male broilers (Table 3; Fig. 1). As noted in the previous results from our laboratory, a reduction in the dietary crude protein to

Table 1: Composition (%) of diets with different levels of crude protein

Ingredient	CP (%)				
	24	22	20	18	16
Yellow corn	48.41	54.45	60.77	68.42	78.36
Dehulled soybean meal	39.89	34.67	27.96	20.12	8.91
Dicalcium phosphate	2.22	2.22	2.17	2.14	2.09
Poultry oil	7.27	6.30	5.35	3.93	1.83
Ground limestone	0.89	0.94	1.00	1.06	1.16
Sodium chloride	0.38	0.38	0.38	0.38	0.38
Sodium bicarbonate	0.20	0.20	0.20	0.20	0.20
Potassium carbonate	0.00	0.00	0.06	0.44	0.99
Vitamin premix[1]	0.20	0.20	0.20	0.20	0.20
Trace mineral premix[2]	0.10	0.10	0.10	0.10	0.10
Choline chloride (60%)[3]	0.20	0.20	0.20	0.20	0.20
L-Lysine Hcl	0.00	0.00	0.23	0.51	0.92
L-Arginine	0.00	0.00	0.16	0.41	0.78
DL-Methionine	0.24	0.29	0.37	0.46	0.58
L-Threonine	0.00	0.05	0.16	0.29	0.49
L-Valine	0.00	0.00	0.10	0.25	0.48
L-Isoleucine	0.00	0.00	0.09	0.24	0.47
L-Phenylalanine	0.00	0.00	0.00	0.13	0.56
L-Leucine	0.00	0.00	0.00	0.00	0.19
L-Tryptophan	0.00	0.00	0.00	0.02	0.11
L-Histidine	0.00	0.00	0.00	0.00	0.09
Glycine	0.00	0.00	0.00	0.00	0.41
Variable[4]	0.00	0.00	0.50	0.50	0.50
Total	100.00	100.00	100.00	100.00	100.00

[1]Provides per kg of diet: Vitamin A (from vitamin A acetate) 7714 IU; cholecalciferol 2204 IU; vitamin E (from dl-alpha tocopheryl acetate) 16.53 IU; vitamin B_{12} 0.013 mg; riboflavin 6.6 mg; niacin 39 mg; pantothenic acid 10 mg; menadione (from menadione dimethylpyrimidinol) 1.5 mg; folic acid 0.9mg; thiamin (from thiamine mononitrate) 1.54 mg; pyridoxine (from pyridoxine hydrochloride) 2.76 mg; d-biotin 0.066 mg; ethoxyquin 125 mg; Se 0.1 mg. [2]Provides per kg of diet: Mn (from $MnSO_4 \cdot H_2O$) 100 mg; Zn (from $ZnSO_4 \cdot 7H_2O$) 100 mg; Fe (from $FeSO_4 \cdot 7H_2O$) 50 mg; Cu (from $CuSO_4 \cdot 5H_2O$) 10mg; I (from $Ca(IO_3)_2 \cdot H_2O$) 1 mg. [3]Provides 1040 mg/kg supplemental choline. [4]Variable amounts of amino acids and corn starch.

levels lower than 22% resulted in a significant reduction in the BW gain and an increase in the FCR even though the low CP diets were formulated to provide a minimum of 110% of NRC (1994) amino acid recommendations. Addition of a mixture of EAA to bring total dietary levels equal to that of the 22% CP diet improved performance slightly when added to the 20% CP diet and significantly when added to diets with 16 or 18% CP. Chicks fed the EAA-supplemented 18 and 20% CP diets did not differ significantly in BW from those fed the 22% CP diet but were significantly lighter than those fed the 24% CP diets. Addition of the mixture of NEAA to equal the N content of the EAA mixture also improved the BW of chicks fed the 20% and 16% CP diets but had no effect on BW of chicks fed the 18% CP diet.

Reduction in dietary CP had a significant effect on feed conversion by male broilers (Table 3; Fig. 2). Decreasing the dietary CP resulted in significant increases in FCR at each reduction in dietary CP level. Addition of a mixture of EAA to bring total dietary levels equal to that provided by the 22% diet had no significant effect when added to the diet with 20% CP but significantly improved performance when added to diets with 16 or 18% CP. The FCR of birds fed the 18% CP diet supplemented with the EAA mixture did not differ significantly from that of birds fed the 22% CP diet but was significantly less than that of birds fed the diet with 24% CP. The improvement in FCR of chicks fed the 16% CP diet supplemented with the EAA mixture was equal to that obtained on the 18% CP diet but was less than that obtained on diets with 22 or 24% CP.

Addition of the NEAA mixture to provide N equivalent to that from the EAA mixture had variable results. There was no apparent benefit observed when added to diets with 20% CP but a significant improvement when added to diets with 18% CP. Addition to the diet with 16% CP resulted in a numerical but nonsignificant improvement in FCR.

The nitrogen excretion significantly decreased as the CP levels declined, but was increased by the addition of mixtures of EAA or NEAA at each level of CP (Table 3; Fig. 3). The increased N excretion that resulted from addition of the mixtures of EAA or NEAA suggests that the supplements were not totally used to support protein

Table 2: Nutrient analysis of diets (% of air-dry sample)

Nutrient	CP (%)							
	24	22	20	18	16	20[1]	18[2]	16[3]
CP (C)[4]	24.00	22.00	20.00	18.00	16.00	20.89	19.70	18.07
CP (A)[5]	24.00	21.50	20.48	17.77	15.53	20.81	19.36	17.14
Met (C)	0.60	0.63	0.67	0.72	0.78	0.67	0.72	0.78
Met (A)	0.65	0.62	0.74	0.67	0.65	0.71	0.72	0.80
TSAA (C)	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99
TSAA (A)	1.06	0.99	1.08	0.96	0.87	1.04	1.01	1.01
Lys (C)	1.36	1.21	1.20	1.20	1.20	1.20	1.20	1.20
Lys (A)	1.47	1.22	1.26	1.32	1.27	1.21	1.21	1.27
Trp (C)	0.34	0.30	0.25	0.22	0.22	0.30	0.30	0.30
Trp (A)	0.26	0.22	0.20	0.19	0.17	0.24	0.24	0.25
Thr (C)	0.92	0.88	0.88	0.88	0.88	0.88	0.88	0.88
Thr (A)	1.00	0.90	0.92	0.88	0.83	0.91	0.90	0.91
Ile (C)	1.02	0.92	0.88	0.88	0.88	0.92	0.92	0.92
Ile (A)	1.08	0.92	0.91	0.85	0.80	0.92	0.90	0.88
His (C)	0.64	0.59	0.51	0.43	0.39	0.59	0.59	0.59
His (A)	0.68	0.61	0.54	0.47	0.40	0.61	0.61	0.66
Val (C)	1.12	1.02	0.99	0.99	0.99	1.02	1.02	1.02
Val (A)	1.17	1.01	1.04	0.96	0.94	1.01	1.01	0.97
Leu (C)	2.04	1.90	1.70	1.47	1.32	1.90	1.90	1.90
Leu (A)	2.08	1.85	1.68	1.51	1.28	1.86	1.89	1.85
Arg (C)	1.64	1.46	1.41	1.40	1.40	1.46	1.46	1.46
Arg (A)	1.79	1.52	1.50	1.44	1.29	1.53	1.49	1.52
Gly (C)	1.01	0.92	0.80	0.66	0.86	1.06	1.24	1.49
Gly (A)	1.05	0.91	0.82	0.69	0.78	1.06	1.25	1.54
Ser (C)	1.21	1.10	0.95	0.77	0.52	0.95	0.77	0.52
Ser (A)	1.30	1.12	1.01	0.87	0.60	0.99	0.83	0.55
Gly+Ser (C)	2.22	2.01	1.75	1.43	1.38	2.01	2.01	2.01
Gly+Ser (A)	2.35	2.03	1.83	1.56	1.38	2.05	2.08	2.09
Phe (C)	1.16	1.05	0.91	0.88	1.07	1.16	1.29	1.48
Phe (A)	1.24	1.09	0.96	0.92	1.00	1.09	1.35	1.60
Tyr (C)	0.92	0.84	0.73	0.60	0.41	0.73	0.60	0.41
Tyr (A)	0.73	0.65	0.51	0.49	0.30	0.54	0.47	0.30
Phe+Tyr (C)	2.08	1.89	1.64	1.48	1.48	1.89	1.89	1.89
Phe+Tyr (A)	1.97	1.74	1.47	1.41	1.30	1.63	1.82	1.90

[1]20% CP plus essential amino acids equal to 22% diet. [2]18% CP plus essential amino acids equal to 22% diet.
[3]16% CP plus essential amino acids equal to 22% diet. [4]Calculated values from NRC (1994).
[5]Analyzed values from Ajinomoto Heartland Lysine LLC, Chicago IL 60631.

accretion but were being excreted.

These results indicate that problems encountered in diets with low levels of CP might be overcome through more EAA supplementations as we observed at the 20% CP diet and the 18% CP diet. This may also indicate that the NRC (1994) recommendations for some EAA are not sufficient when the CP levels in diets decrease. However, adding sufficient amounts of essential amino acids to the 16% CP diet and bringing essential amino acids in the diet up to content same as the 22% CP diet did not totally overcome the adverse effects of the low CP diet. In a like manner, the addition of an equivalent amount of nitrogen in the form of a mixture of NEAA had limited effects compared with the EAA supplementation.

This research suggests that the growth performance may be maintained when dietary protein levels are moderately reduced and diets are supplemented with the EAA (Daghir, 1983; Han *et al*., 1992; Morris *et al*., 1992; Deschepper and DeGroote, 1995). However, a further reduction in CP levels still has a detrimental effect on the performance that cannot be overcome by simple additions of EAA or NEAA mixtures. Further experiments should be carried out to examine the possibility of more varieties and quantities of the EAA supplementations to the diet low in CP to improve the performance of chicks fed the low CP diet.

Stucki and Harper (1961) pointed out the importance of providing NEAA in diets with low crude protein. They

Table 3: Effects of dietary CP level and supplementation with essential (EAA) and nonessential (NEAA) amino acids on performance and nitrogen excretion (NE)

CP (%)	Description	21 d BW (g)	0-21 d FCR (g/g)	0-21 d Mortality (%)	18-d Fecal N[3] (%)
24	Minimum 110% of NRC	742[a]	1.288[a]	1.1	4.86a
22	Minimum 110% of NRC	719[ab]	1.326[b]	0.0	4.45b
20	Minimum 110% of NRC	679[c]	1.367[cd]	4.2	3.78ef
18	Minimum 110% of NRC	627[d]	1.441[e]	4.2	3.61fg
16	Minimum 110% of NRC	516[f]	1.485[f]	0.0	2.90h
20	+ EAA[1]	700[bc]	1.366[cd]	4.5	4.07d
18	+ EAA[1]	695[bc]	1.348[bc]	4.2	3.86e
16	+ EAA[1]	567[e]	1.431[e]	8.3	3.51g
20	+ NEAA[2]	703[bc]	1.372[cd]	4.2	4.29bc
18	+ NEAA[2]	624[d]	1.391[d]	8.3	4.17cd
16	+ NEAA[2]	588[e]	1.455[ef]	6.3	3.47g
Probability > F		0.0001	0.0001	0.20	0.001
Coefficient of variation		5.14	2.89	4.154	3.25

[1]Provides a mixture of Trp, Ile, His, Val, Leu, Arg, Gly, and Phe to equal level provided in diet with 22% CP.
[2]Provides a mixture of Ala, glutamic acid and glutamine isonitrogenous to EAA mixture added to same CP level.
[3]Percent of dry matter. [4]CV of transformed means. a-g means within column with no common superscripts differ significantly (P < 0.05).

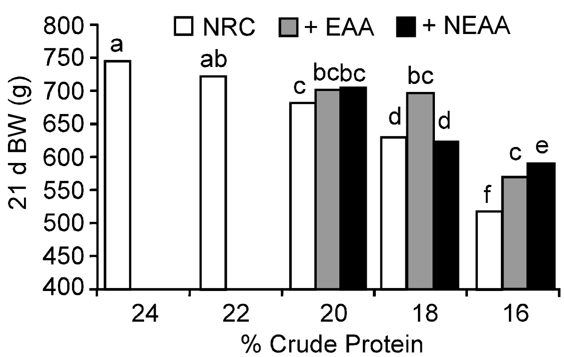

Fig. 1: Effects of addition of mixtures of essential amino acids (EAA) or nonessential amino acids (NEAA) to diets with reduced levels of crude protein on body weight of male broilers.

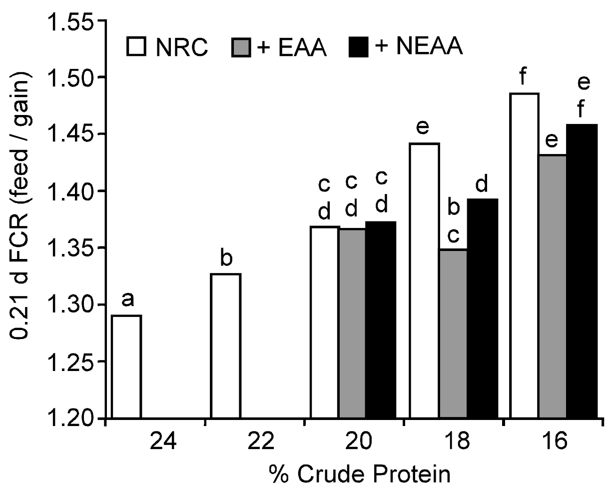

Fig. 2: Effects of addition of mixtures of essential amino acids (EAA) or nonessential amino acids (NEAA) to diets with reduced levels of crude protein on feed conversion by male broilers.

noted that about 33% of the dietary nitrogen had to be provided from NEAA in order to obtain maximum growth of broiler chickens. Sugahara and Ariyoshi (1968) pointed out that Stucki and Harper (1961) neglected the difference of DL-form of amino acids in their control diet, and calculated that optimum performance of broilers could be achieved when dietary NEAA ranged from 40 to 50% of the dietary nitrogen. Bedford and Summers (1985) confirmed that in all cases, apart from the proportion of carcass protein, optima were achieved at the 55:45 EAA/NEAA ratio. The ratio of EAA/NEAA has also been studied with rats (Heger, 1990), pigs (Wang and Fuller, 1989), turkeys (Bedford and Summers, 1988), and kittens (Rogers *et al*., 1998). Except for kittens, results of the other three species have shown optimal growth rates when the dietary EAA/NEAA ranging from 40:60 to 65:35. Minimal response was noted to the supplementation of diets in the present study with NEAA. A similar lack of response to supplementation of low CP diets with NEAA has been observed by Kerr and Kidd (1999).

Although all the essential amino acids levels in diets used in this study are above NRC (1994) recommended levels most of them tend to decline towards their minimum requirements as dietary CP levels decreases. It is possible that some essential amino acids whose requirements are based on limited studies, such as Gly and Ser, may become limiting. In comparison to the 1.25% level of Gly + Ser suggested by NRC (1994),

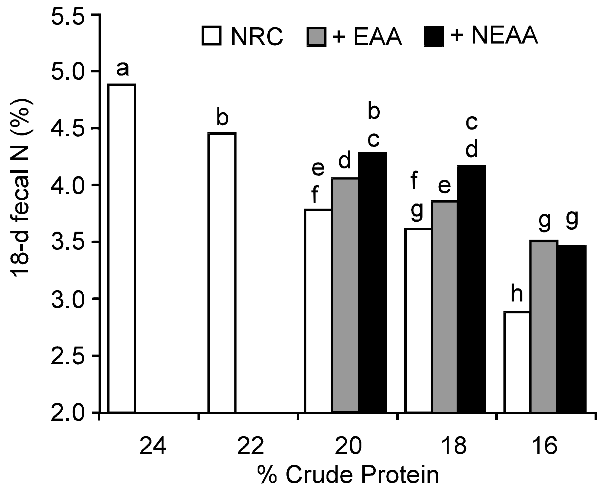

Fig. 3: Effects of addition of mixtures of essential amino acids (EAA) or nonessential amino acids (NEAA) to diets with reduced levels of crude protein on fecal nitrogen content of male broilers

Heger and Pack (1996) reported that Gly and Ser needs ranged from 1.5 to 1.6% at 17% CP up to 1.7to 1.8% at 23% CP. Schutte *et al*. (1997) recommended 1.9% of total Gly and Ser when birds were fed low CP diets fortified with amino acids. Jiang *et al*. (2005) reported that addition of Gly to diets low in CP resulted in improved performance and concluded that it is preferable to maintain a higher level of Gly than recommended by NRC (1994) as the dietary CP level is reduced. This is in agreement with Almquist and Grau (1944), Douglas *et al*. (1958), Waterhouse and Scott (1961) and Ngo and Coon (1976).

Reasons for the reduction in performance at low dietary CP levels have not been totally explained. At the present time it is not likely that merely adding more EAA or NEAA will enable the use of diets much lower in CP than typically used in commercial diets today. More research needs to be done on needs for individual amino acids in diets low in CP, especially for amino acids other than Lys and Met.

References

Almquist, H.J. and C.R. Grau, 1944. The amino acid requirements of the chick. J. Nutr., 28: 325-331.

Association of Official Agricultural Chemists, 1970. Official Methods of Analysis. 11th ed. Association of Official Agricultural Chemists, Washington, DC.

Bedford, M.R. and J.D. Summers, 1985. Influence of the ratio of essential to nonessential amino acids on performance and carcase composition of the broiler chick. Br. Poult. Sci., 26: 483-491.

Bedford, M.R. and J.D. Summers, 1988. The effect of essential to nonessential amino acid ratio on turkey performance and carcass composition. Can. J. Anim. Sci., 68: 899-906.

Deschepper, K. and G. DeGroote, 1995. Effect of dietary protein, essential and non-essential amino acids on the performance and carcass composition of male broiler chickens. Br. Poult. Sci., 36: 229-245.

Daghir, N.J., 1983. Effect of lysine and methionine supplementation of low protein roaster diets fed after six weeks of age. Poult. Sci., 62: 1572-1575.

Douglas, C.R., H.J. Hochreich and R.H. Harms, 1958. Glycine in broiler nutrition. Poult. Sci., 37: 620-624.

Fancher, B.I. and L.S. Jensen, 1989a. Influence on performance of 3 to 6-wk-old broilers of varying dietary protein contents with supplementation of essential amino acid requirements. Poult. Sci., 68: 113-123.

Fancher, B.I. and L.S. Jensen, 1989b. Dietary protein level and essential amino acid content: Influence upon female broiler performance during the grower period. Poult. Sci., 68: 897-908.

Fancher, B.I. and L.S. Jensen, 1989c. Male broiler performance during the starting and growing periods as affected by dietary protein, essential amino acid and potassium levels. Poult. Sci., 68: 1385-1395.

Federation of Animal Science Societies, 1999. Guide for the Care and Use of Agricultural Animals in Agricultural Research and Teaching. 1st rev. ed. Federation of Animal Science Societies, Savoy IL.

Fraps, G.S., 1943. Relation of protein, fat, and energy of the ration to the composition of chickens. Poult. Sci., 22: 421-424.

Han, Y., H. Suzuki, C.M., Parsons and D.H. Baker, 1992. Amino acid fortification of a low-protein corn and soybean meal diet for chicks. Poult. Sci., 71: 1168-1178.

Heger, J., 1990. Non-essential nitrogen and protein utilization in the growing rat. Br. J. Nutr., 64: 653-661.

Heger, J. and M. Pack, 1996. Effects of glycine + Serine on starting broiler chick performance as influenced by dietary crude protein levels. Agribio. Res., 49: 257-265.

Jiang, Q., P.W. Waldroup and C.A. Fritts, 2005. Improving the utilization of diets low in crude protein for broiler chickens. 1. Evaluation of special amino acid supplementation to diets low in crude protein. Int. J. Poult. Sci., 4: 115-122.

Kerr, B.J. and M.T. Kidd, 1999. Amino acid supplementation of low-protein broiler diets: 1. Glutamic acid and indispensable amino acid supplementation. J. Appl. Poult. Res., 8: 298-309.

Lipstein, B. and S. Bornstein, 1975. The replacement of some of the soybean meal by the first limiting amino acids in practical broiler diets. 2. Special additions of methionine and lysine as partial substitutes for protein in finisher diets. Br. Poult. Sci., 16: 189-200.

Lipstein, B., S. Bornstein and I. Bartov, 1975. The replacement of some of the soybean meal by the first limiting amino acids in practical broiler diets. 3. Effects of protein concentration and amino acid supplementation in broiler finisher diets on fat deposition in the carcass. Br. Poult. Sci., 16: 627-635.

Morris, T.R., R.M. Gous and S. Abebe, 1992. Effects of dietary protein concentration on the response of growing chicks to methionine. Br. Poult Sci., 33: 795-803.

National Research Council, 1994. Nutrient Requirements of Poultry. 9th revised ed. Natl. Acad. Sci., Washington, DC.

Ngo, A., and C.N. Coon, 1976. The effect of feeding various levels of dietary glycine in a pre-experimental diet to one-day old chicks on their subsequent glycine + serine requirement. Poult. Sci., 55: 1672-1677.

Rogers, Q.R., T.P. Taylor and J.B. Morris, 1998. Optimizing dietary amino acid pattern at various levels of crude protein for cats. J. Nutr., 128: 2577s-2580s.

SAS Institute, 1991. SAS User's Guide: Statistics, Version 5 (Cary, NC, SAS Institute).

Schutte, J.B., W. Smink and M. Pack, 1997. Requirement of young broiler chicks for glycine + serine. Arch. Geflugelkd., 61: 43-47.

Si, J., C.A. Fritts, D.J. Burnham and P.W. Waldroup, 2004. Extent to which crude protein may be reduced in corn-soybean meal broiler diets through amino acid supplementation. Int. J. Poult. Sci., 3: 46-50.

Stucki, W.P. and A.E. Harper, 1961. Importance of dispensible amino acids for normal growth of chicks. J. Nutr., 74: 377-383.

Sugahara, M. and S. Ariyoshi, 1968. The role of dispensible amino acids for the maximum growth of chick. Agri. Biol. Chem., 32: 153-160.

Waldroup, P.W., R.J. Mitchell, J.R. Payne and K.R. Hazen, 1976. Performance of chicks fed diets formulated to minimize excess levels of essential amino acids. Poult. Sci., 55: 243-253.

Wang, T.C. and M.F. Fuller, 1989. The optimum dietary amino acid pattern for growing pigs. 1. Experiment by amino acid deletion. Br. J. Nutr., 62: 77-89.

Waterhouse, H.N. and H.N. Scott, 1961. Effect of different proteins and protein levels on the glycine needs of the chick fed purified diets. Poult. Sci., 40: 1160-1165.

Uzu, G., 1982. Limit of reduction of the protein level in broiler feeds. Poultry Sci. 61 (Abstr.): 1557-1558.

Uzu, G., 1983. Broilers feed reduction of protein level during finishing period. Effect on performance and fattening. A. E. C. Information No. 242. Rhone-Poulenc Publishers, Commentary 03600, France.

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